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by

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Military Application and Future Development of Optical Computer

Zhang, Chang-Guo

Optical computer, with the capability of super-parallel, super-speed, super-capacity, interference-free, and error-tolerance, is a product of the modern optical technology. In the 21st century, optical computer will gradually take the place of electronic computer in specialized fields such as military and advanced technology and become a one and only computational equipment.

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The development of VLSI has met the "bottle-neck" effect as von Neuman had described. Limitations such as clock distortion, conducting wire resistance, capacitor distribution, and wiring packing have prevented significant decrease in computational speed. At the same time, the /64 peculiar serial structure has limited precision treatment to only some of the characteristic quantities, and treatment of simple random problems was out of the question. For applications such as military and advanced technologies, computational device with big capacity, high speed, miniaturized size and artificial intelligence is necessary. The characteristics of optical systems and the recent development of optical devices have made optical computer the promising second-generation computer.

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

The idea of optical computer was proposed by IBM in 1964. However, research toward realization of optical computer became a lot more popular only after the invention of optical double-steady-state crystal in 1979. At present, major industrialized nations in the world have invested much manpower and funding in this field of research. Major sources of funding are from military and interested commercial groups. The first optical numerical computer was manufactured by Bell Lab in 1990, indicating the possibility of realizing optical computers. It has been estimated that the impact of optical computer will be equal to the invention of aircraft by the Wright brothers. The first practical optical computer should be available in 10 years and become commonplace in the next century.

Characteristics of Optical Computers

Optical computers are the computers which carry out calculation with optical signals. Similar to electronic computers, optical computers also have optical switch, optical diode, optical storage device, feedback device and integrated optical circuit and are capable of computation, amplification, storage, and feed back. Optical computers usually have the following special features:

Super Parallarity: This ability would allow handling two-dimensional images simultaneously. There is no interference when many light beams pass through the same optical element. A good lens can provide 10^7 to 10^8 channels. The number of mutual

connections for a typical optical system is 10^{12} and the number of mutual connections per second is 10^{17}. These figures are much higher than the corresponding figures of an electronic system, averaging 10^4 and 10^8, respectively, and are close to human brains.

Super Calculation Capability: The switching time of a practical optical switch is 10^{-12} sec, about 10^3 times faster than an electronic switch. Therefore, the speed of optical computer will be roughly 10^3 faster than electronic computers.

Error Tolerance: Because optical computers simulate the nervous network system of human brains it possesses the error tolerance capability owned by human brains. The computation will not be affected even one of the optical elements has received damage or becomes defective.

Big Capacity: The band width of an optical computer can be as wide as 10^{12}Hz.

Interference-Free Operation: Optical computers are not interfered by any external electromagnetic interferences. Neither is there any quantum noise limitations.

Structure, Algorithm and Element of Optical Computer Systems

Just as von. Neuman structure, Bull logic algorithm, and silicon semiconductor and the VLSI circuitry are the foundation of modern electronic computers, the reasonable structure, algorithm and elements are the three key issues in the optical computer studies.

At present, all the structures proposed for optical computers are all under investigation. Generally, a future optical computer system should possess the following features:

(1) A computational tool; capable of multiple-function parallel processing, as opposed to single-function processing system. /65

(2) Parallel input and output.

(3) Parallel and interchangeable optical inter-connection.

(4) A feedback system; capable of multiple computation and compensation for optical loss problem.

(5) Capability of programming processing; allowing change of inter-connection mode and the necessary computation mode.

The choice of any one of the four computation modes: time-sequence digital computation, parallel digital computation, parallel simulation computation, and parallel mixture of simulation/digital computation modes should be made available.

At present, there are three major development directions for optical computers. First, optical electronic computer, inheriting the structure of electronic computer with time-sequence computation mode while adopting optical elements instead of electronic elements. Second, parallel optical computer, including parallel digital optical computer and parallel simulation optical computer. Recent research emphasis is mainly focused on the parallel digital optical computer. Third, neuro-network optical computer, utilizing optical elements to simulate the structure of human brain and capable of artificial intelligence reasoning.

Figure 1 shows the basic optical elements for an optical computer. The key element is the optical logic element. Suitable choice of material for the logic gate of the optical transistor is the most important issue, and the weakest link in recent studies. The most possible device for optical transistor is the Fabrie-Lobo interferometer or standardized device. Suitable materials for this device are the non-linear semiconductor materials such as GaAs which is capable of high speed operation in room temperature. The NOR gate response time is between 1 and 3 μμS and recovery time is less than 100μμS and is regarded as a hopeful future "optical silicon".

Military Application of Optical Computers

Military application is one of the incentives for developing optical computers. The research of optical computers in USSR and USA both have military application as one of the major objectives. In the near future, optical computers will play a major role in many specialized military fields.

Radar Signal Processing

Processing of radar signals involves high input rate, large bandwidth and real time processing - an increasingly demanding requirement for electronic computers. Because traditional method of radar signal processing is similar to optical computation, optical computer is an ideal tool for radar signal processing. The initial study of optical computer - optical signal

processing, was closely related to this field. Typical device is the radar alarming receiver equipped with audio-optical devices such as the ALR-67(V) of USA.

Composite aperture radar image recovery processing involves computation with 10^9 matrix, which is also the application of optical computers.

High-Precision Simulation Experiment

Accompanying the development of modern technology, the simulation of weapons and tactics of modern war theater is becoming more and more complicated and large-capacity high-speed computer is necessary for data processing. A typical example is the design of aircraft and avionic devices which uses simulation technology to transform digital models for three-dimensional simulation. Typical speed requirement is on the order of 10^{10}/sec. Furthermore, data processing for wind tunnel test of a few tens of thousands hours also require large-capacity computation capability. At present, only a few of the super computers are marginally capable of task of this kind while optical computer can easily fulfill requirement for this type of computations.

SDI Project

One of the key technology obstacles of the SDI project is the BMC^3 system; namely, the battle, manage, command, control, and communication system. To precisely distinguish and track

multiple (may be a few hundred) targets and intercept at various levels, a super computer with ultra high data processing capability is necessary. The 1 BIP (billion per second) modern electronic computer can marginally fulfill the mission of target capture and tracking but can not fulfill the computation speed requirement of 10^2 - 10^3 BIP of the C^3 system. Research of optical computer is one of the major programs of this project.

High-Speed Image Processing and Mode Distinguishing

The foundation of high-precision investigation and real-time distinguishing of military targets is image processing. Because the quantity of data involved in images captured by modern optical-electronic transducers is large, the speed and precision requirement of processing is becoming higher and higher and a new breed of computer is necessary. At present, the real-time TV image processing speed is 7.3×10^{10} floating point/sec and the best modern computer can only provide medium image distinguishing quality. Therefore, one of the development directions of optical computer is intelligent image processing and image distinguishing.

Fire-Control and Guidance of Complicated Weapon Systems

Modern fire-control systems generally use multiple-group multiple-quantity transducers such as the various radars and opto-electronic detectors on naval vessels. Because large quantity of data can be gathered, accurate and fast command and

response depends on real-time processing of collected data. As a result, optical computers is an important computational device sought by military for fire-control purpose. The research of optical computer by US Naval Weaponry Laboratory was based on the requirement of fire-control systems on naval warships.

The guidance of medium-to-long range ballistic missiles is also the application of optical computers. The image-guidance war head available now is the prototype of the future intelligence-guidance war heads.

Present Situation and Development Trend

Present Situation

Research of optical computer is becoming popular and some of the best scholars are now involved. At present, the leading technology is possessed by European nations and USA. /66

United States is one of the first nations which started the optical computer research and the current research activities can be categorized into two major groups. The first group is an optical circuit research center headed by the University of Arizona. This research group is closely tied to industries and most of its funding is from National Science Foundation and related manufacturing sectors, industries and personal giving. The second group is a cooperated optical computer research organization sponsored by the Department of Defense and coordinated by SDI project. Its members, composed of 8 formal organizational members and 9 associate members, include Naval

Laboratory and its European associate Oriott-Watt University. Since 1985, US DoD has contributed more than 10 million dollars into this project.

On the other hand, an 8-year (1988-1995) project organized by the Department of Defense, which has also invested 400 million dollars under the grant allocated by DARPA, is devoted to the neuro-network and its related research topics. Part of the funding under this project was used in development of optical materials and optical neuro-network systems.

Furthermore, both University of Pennsylvania and California Institute of Technology have devoted its manpower in the research of radar signals using neuro-network processors while Carnegie-Mellon University and Dayton University have been focusing on optical mode distinguishing and related guidance problems.

The group led by Allen Huang of the Bell Laboratory of AT&T is probably the first group that has demonstrated most technical achievement. The first optical switching device - spontaneous opto-electronic effect device (SEED), made of GaAs and Al-Ga-As laminate and capable of similar functions of an electronic transistor was successfully developed in 1986. The first digital optical processor made of "SEED" was manufactured in January, 1990. This processor is $1m^2$ in area and 30cm in thickness, with a computation speed of 10^7/sec. So far, this group is working on the manufacturing of full-function optical system and the major goal is to use optical wave guide to replace lens and mirrors to achieve optical inter-connection.

The optical computer research program in Europe is a project involving many nations. In 1983, European Community set up the "European United Optical Double-Steady-State Project" and major participating organizations include Universities and Laboratories from England, France, West Germany, Italy, and Belgium. Under the leadership of Prof. Mandel of Brusell Liberty University and Prof. Smith of Oriott-Watt University, the theoretical research of optical double-steady state of Europe has enjoyed the leading role for a long time. Its experimental research is also competing with that of the US. The first prototype optical processor experimental device, shown in Hannovah Expo in 1987, was manufactured by this European group.

The optical computer research in Japan was started a little bit late. However, through governmental sponsorship and industrial support, this field has already attracted much attention.

In 1985, a "Basic Optical Computer Compound Research" project was established in Japan and optical computer has attracted the attention from both the government and industry. Later, a "Optical Computer Research Committee" was established and optical computer was placed above electronic technology as the ultra-advanced technological topic. The emphasis of Japanese research was placed on optical path elements and integrated light path. Major participating groups include the Electronic Technology Research Institute, Tokyo Technology Institute, Osawa University, and Mitsubishi Corporation. In 1989, an optical

neuro-computer prototype, made of 32 neuro-elements and capable of symbol distinguishing, was manufactured by Mitsubishi.

The research of optical computer in Soviet Union was started in mid-70's and many technological breakthroughs, both in double-steady-state theory and optical elements, were obtained. Similar to the US, the Russian government also pays a great deal of attention to the research of optical computer because of its potential military applications. One of the major participating groups is Lenninggrad Physics Technology Institute which produced a optical switch with switching time of 10^{-11} sec.

In 1984, a "Chinese Optical Computer Promoting Society" was founded in SiAnne and more than 10 universities and institutes are now participating in research of related subjects.

Development Trend

The future of optical computer research will be focused on the suitable materials for "optical silicon" which will improve the characteristics of key optical elements.

The future computers will be composed solely of optical elements. However, because both optical and electronic computers have their special features the more recent optical computers will be a combination of optical and electronic technologies.

Digital optical computer is the major form of future optical computers. Simulation optical computer will be mainly used in mode distinguishing, brain simulation and intelligent signal processing.

The major part of the future intelligent optical computers will be the optical neuro-network and the research emphasis is on the optical neuro-network model, optical inter-connection, and hardware realization.

At present, the status of optical computer is somewhat similar to the electronic computer in the 40's when the technology was still at its infant stage. The first full-functional optical computer should be manufactured in the next 5 to 10 years and by the early next century all types of specialized optical computers will be commercialized and reached an annual sales goal of approximately 10 billion dollars.

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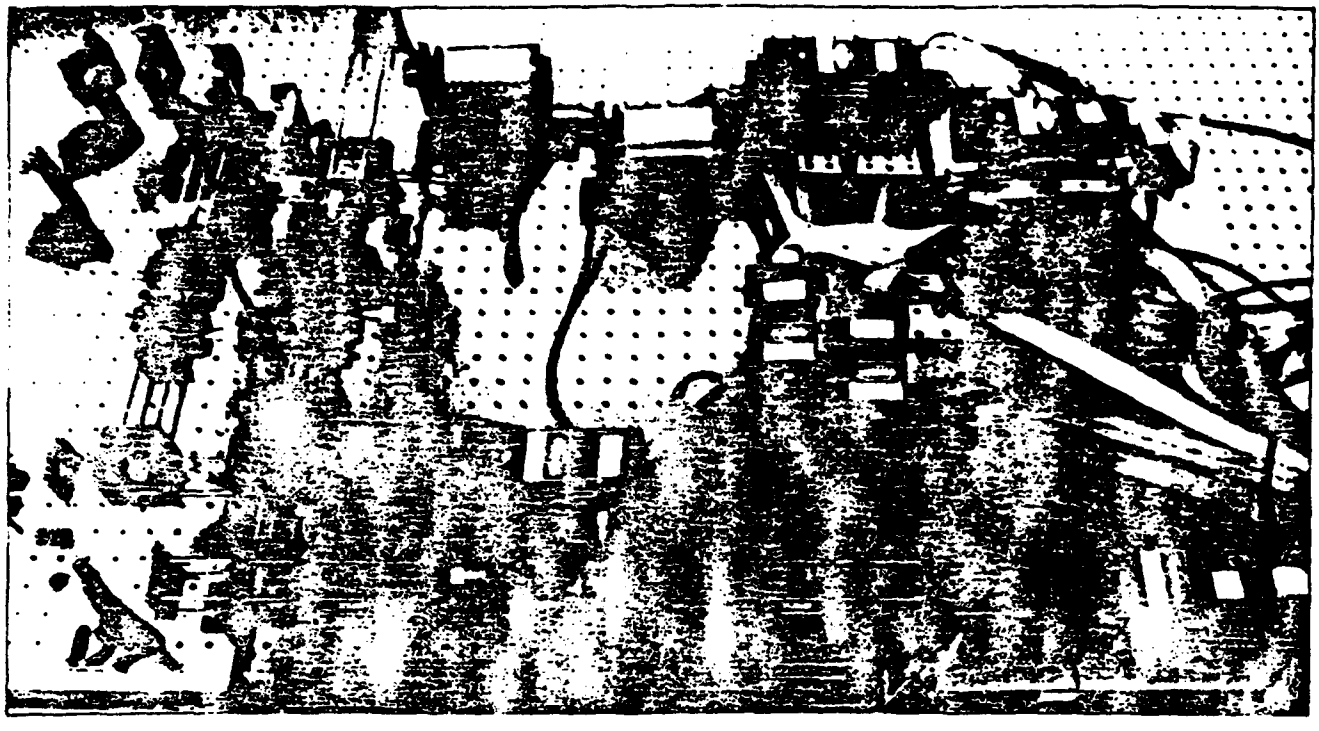
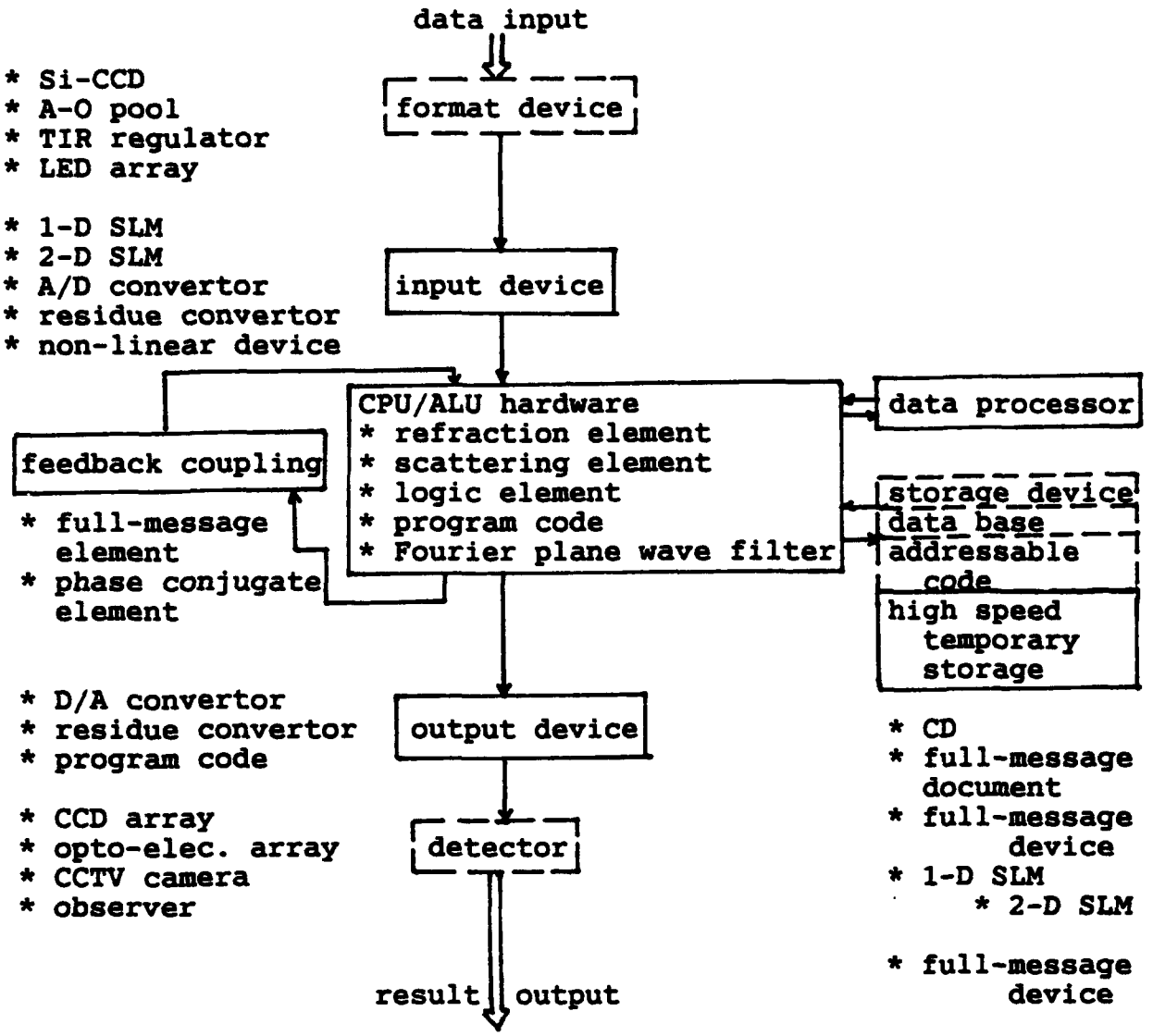
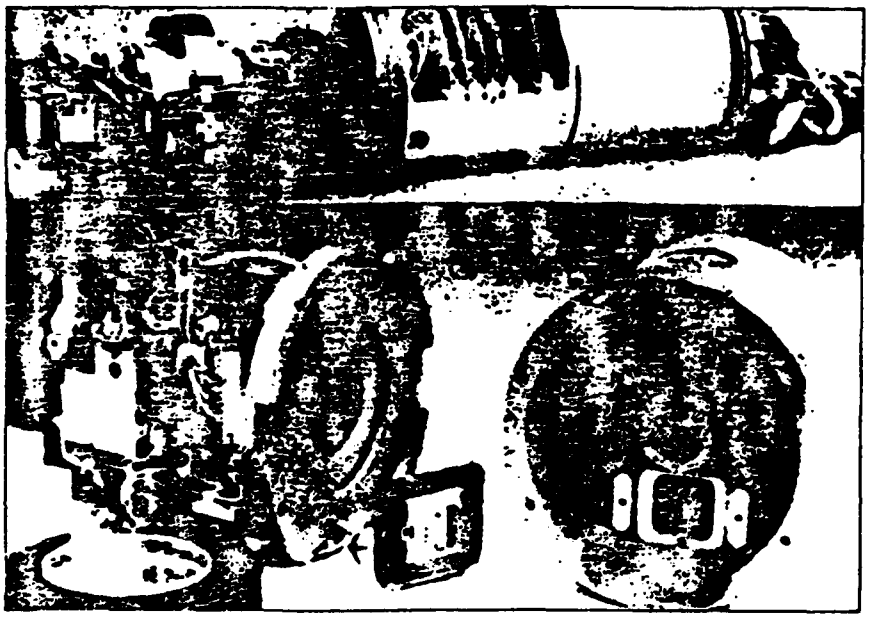


Illustration of programmable optical logic device

Elements of A Optical Computer





A compact optical guide head manufactured by JPL and Parkin-Elmer Company for British Army Guided Missile Command. The device is 75mm in length, 100mm in diameter and is equivalent to a dedicated simple optical computer.

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